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TiO_2/SiO_2 and ZrO_2/SiO_2 MULTILAYER MEDIA FILM OPTICAL LOSS AND LASER DAMAGE STUDY

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Wu Zhouling Fan Zhengxiu

ABSTRACT

Taking TiO_2/SiO_2 and ZrO_2/SiO_2 multilayer media films as examples, measurements were done, with different technical conditions and different film system structures, of thin film sample optical losses as well as laser loss threshold values. At the same time, preliminary research and discussion was done with regard to experimental results.

KEY WORDS Optical Thin Films, Laser Damage, Optical Loss

I. INTRODUCTION

A certain optical loss exists in any optical thin film. This type of loss includes the two divisions of absorption and scattering. They both have close relationships with laser damage associated with thin films [1,2]. As far as accurately understanding this type of relationship and its mechanisms is concerned, it is helpful to carry a step further revelation of laser damage mechanisms associated with optical thin films, raising film layer optical quality. The article in question is based on this objective. Using TiO_2/SiO_2 and ZrO_2/SiO_2 multilayer media reflection films as examples, study--with different technical conditions and different film system structures--thin film optical losses and laser damage threshold values. In conjunction with this, make preliminary inquiries into relationships between the two as well as relevant mechanisms.

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* Numbers in margins indicate foreign pagination. Commas in numbers indicate decimals.

II. EXPERIMENTAL METHODS

Samples were uniformly evaporation plated on K_9 glass substrate. Relevant film system design and technical conditions are as shown in Table 1.

As far as thin film absorption measurements are concerned, option is made for the use of photothermal deflection techniques [3.4]. The experimental equipment lay out is a collinear type, that is, pump light (Nd:YAG, λ = 1.06 μm) and survey probe light (He-Ne λ = 632nm) are mutually parallel. In conjunction with this, they approach colinearity [4]--for example, as shown in Fig.1.

With regard to using this type of method to measure light absorption associated with multilayer media films, degrees of sensitivity reach A ~ 10^{-5}. Repetition accuracy is better than 10%.

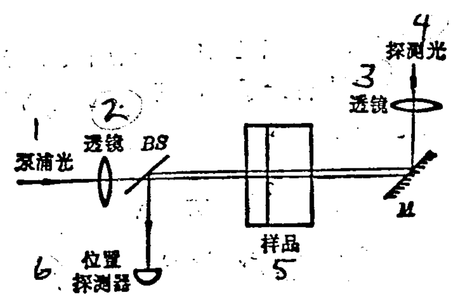

Fig.1 Photothermal Deflection Technique Schematic

Key: (1) Pump Light (2) Lens (3) Lens (4) Survey Probe Light (5) Sample (6) Position Detector

TABLE 1. REFRACTION INDICES ASSOCIATED WITH MEASURED SAMPLE FILM SYSTEM STRUCTURES, TECHNICAL CONDITIONS, AND CORRESPONDING FILM MATERIALS

1 样品序号	2 材料	3 膜系结构	4 制备工艺		5 膜料折射率
S_1	H: TiO_2 L: SiO_2	$A(HL)^3HS$	6 电子束热蒸发	T_S: 冷基板 7 T_A: 室温 8	$n_H=2.46$ $n_L=1.40$
S_2				T_S: 冷基板 7 T_A: 400°C	
S_3				T_S: 200°C T_A: 室温 8	
S_4				T_S: 200°C T_A: 400°C	
S_5		$A(3HL)^3 3HS$		T_S: 200°C T_A: 400°C	
S_6		$A(H3L)^3HS$		T_S: 200°C T_A: 400°C	
S_7	H: ZrO_2 L: SiO_2	$A(HL)^3HS$	6 电子束热蒸发	T_S: 冷基板 7 T_A: 室温 8	$n_H=1.90$ $n_L=1.46$
S_8				T_S: 冷基板 7 T_A: 200°C	
S_9				T_S: 200°C T_A: 室温 8	
S_{10}				T_S: 200°C T_A: 200°C	
S_{11}		$A(3HL)^3 3HS$		T_S: 200°C T_A: 200°C	
S_{12}		$A(H3L)^3HS$		T_S: 200°C T_A: 200°C	

9 T_S: 基板烘烤温度; T_A: 成膜后空气中烘烤温度。

Key: (1) Sample Serial No. (2) Material (3) Film System Structure (4) Preparation Technique (5) Film Material Refraction Index (6) Electron Beam Thermal Evaporation (7) Cold Substrate (8) Room Temperature (9) Ts: Substrate Drying Temperature; TA: Drying Temperature in Air After Film Formation

Thin film total integral scattering measurements were carried out on a laser thin film scattering measurement instrument developed by the institute in question. This instrument uses He-Ne (λ = 632.8nm) laser as light source. It opts for the use of light modulation weak signal synchronous locked phase technology. Sensitivities reach 10^{-5}. Relative measurement errors are better than 15% [5,6].

Laser damage test equipment is as shown in Fig.2. Laser systems are composed of Nd:YAG oscillators and two stage Nd:YAG amplifiers. As far as oscillators are concerned, option is made for LiF crystal Q modulation, small aperture diaphragm selected mode, output wave length 1.06 μm, pulse width (FWHM) 10ns, and operation in single mode configuration. Incident light beams converge on sample surfaces through an anti-image error nonspherical lens (f ≈ 80mm). Facula diameter ($1/e^2$) is 44 μm. Thin film damage status is observed and determined through a high power microscope positioned at the back. In damage tests, on sample surfaces, the same location was only laser irradiated once regardless of whether or not this point showed damage. Thin film damage threshold value definitions are an average of two extreme values, that is, the average value associated with the lowest thin film destruction energy and the highest energy which is not capable of causing thin film damage.

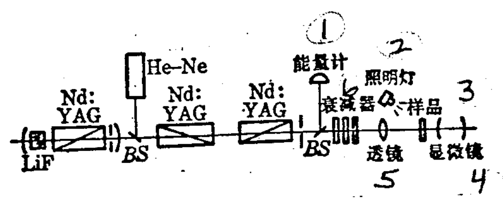

Fig.2 Optical Thin Film Laser Damage Test Equipment Schematic

Key: (1) Energy Meter (2) Illumination Lamp (3) Sample (4) Microscope (5) Lens

III. EXPERIMENTAL RESULTS AND DISCUSSION

Measured thin film sample optical loss and laser damage threshold value test results are as shown in Table 2.

From Table 2, it can be seen that:

1. With regard to TiO_2/SiO_2 multilayer media film systems, when film system structures are the same, thin film optical loss and laser damage threshold values are all clearly related to technical conditions. The key patterns are: (1) Substrate drying aids in improving scattering losses (sample S_4 scattering rates < sample S_2 scattering rates). Moreover, after film formation and drying in air, then, it is possible to clearly reduce absorption rates (S_2 absorption rate < S_1 absorption rate; S_4 absorption rate < S_3 absorption rate); (2) Substrate drying and air drying after film formation both help in raising laser damage thresholds associated with TiO_2/SiO_2 multilayer media films. The later originates with drying clearly reducing absorption. The former, by contrast, may be due to improving film layer micro structure and interior stresses.

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TABLE 2. THIN FILM SAMPLE OPTICAL LOSS AND LASER DAMAGE THRESHOLD VALUE MEASUREMENT RESULTS

1 被测项	2 样品											
	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}
	3 结果											
4 吸收率 (10^{-4})	8.7 ±0.6	7.6 ±0.6	8.8 ±0.5	7.1 ±0.5	9.5 ±0.8	7.6 ±0.7	6.1 ±0.7	5.9 ±0.5	6.0 ±0.6	5.8 ±0.6	9.8 ±1.2	6.2 ±0.6
5 散射率 (10^{-4})	—	4.83 ±0.35	—	3.28 ±0.27	6.53 ±0.72	3.15 ±0.22	—	8.15 ±0.31	—	7.83 ±0.25	12.1 ±0.31	6.65 ±0.19
6 损伤阈值 $(J \cdot cm^{-2})$	8.5 ±2.1	11.5 ±2.2	10.4 ±1.6	13.8 ±1.8	7.0 ±1.6	15.2 ±1.8	11.6 ±3.6	14.2 ±4.1	11.5 ±3.8	16.2 ±1.9	10.3 ±3.1	18.4 ±1.6

Key: (1) Measured Item (2) Sample (3) Results (4) Absorption Rate (5) Scattering Rate (6) Damage Threshold Value

2. In the case of ZrO_2/SiO_2 multilayer media film systems, when film system structures are the same, there is basically no relationship between thin film optical losses and preparation technology. However, laser damage threshold values still obtain clear increases due to drying in air after film formation (S_{10} threshold value > S_9 threshold value, S_8 threshold value > S_7 threshold value). Our understanding of this phenomenon is: Drying not only improves ZrO_2 film crystallization structure. Moreover, it causes the internal stresses between different materials to be eliminated the best. As a result, antilaser damage capabilities are raised.

3. When technical conditions are the same, optical thin film laser damage threshold values clearly depend on film system structure (S_6 threshold values > S_4 threshold values > S_5 threshold values; S_{12} threshold values > S_{10} threshold values > S_{11} threshold values). This is due to increases in high refraction index film layer thicknesses clearly enlarging absorption losses, thus lowering damage threshold values. Moreover, low refraction index film layer thickness increases aid in improving thin film sample boundary surface structures [7] and compensate for thermal stresses produced from the action of strong lasers [8].

From Table 2 it is possible to go a step further in seeing that:

(1) Samples associated with relatively low scattering losses generally possess relatively high damage threshold values. Due to the fact that scattering losses generally characterize sample surface appearance and microscopic structure, the results of this experiment are explained by sample surface appearance and microscopic structure playing a leading role in laser damage on multilayer media films.

(2) Relationships between thin film laser damage and light absorption present a complicated situation. On the one hand, with regard to TiO_2/SiO_2 film systems, damage threshold values generally follow absorption increases and go down. The explanation for this is that absorption plays a leading role in damage processes. This conclusion is in line with our earlier research results on TiO_2 single layer films. On the other hand, in the case of ZrO_2/SiO_2 film systems, under this article's technical conditions, most situations are ones where damage threshold values give rise to clear changes under conditions in which absorption basically does not vary. The explanation for this phenomenon is: in ZrO_2/SiO_2 film system laser damage processes which are studied in this article, what plays the leading role is other factors besides absorption--for example, film layer crystallization structure [10].

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